

# Design of a high power $TM_{01}$ mode launcher optimized for manufacturing by milling

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## Abstract

Recent research on high gradient rf acceleration found that hard metals, such as hard copper and hard copper-silver, have lower breakdown rate than soft metals.

Traditional high gradient accelerating structures are manufactured with parts joined by high temperature brazing. The high temperature used in brazing makes the metal soft, therefore this process cannot be used to manufacture structures out of hard metal alloys. In order to build the structure with hard metals, the components must be designed for joining without high temperature brazing. One method is to build the accelerating structures out of two halves, and joining them by using a low temperature techniques, at the symmetry plane along the beam axis. The structure has input and output rf power couplers. We use a  $TM_{01}$  mode launcher as a rf power coupler, which was introduced during the Next Linear Collider (NLC) work. The part of the mode launcher will be built in each half of the structure.

This paper presents a novel geometry of a mode launcher, optimized for manufacturing by milling. The coupler was designed for the CERN CLIC working frequency  $f = 11.9942$  GHz; the same geometry can be scaled to any other frequency.

## INTRODUCTION

Accelerating gradient is one of the crucial parameters affecting the design, construction and cost of the next generation of linear accelerators. To reach high gradient acceleration above the state of the art of 100 MV/m, several problems such as vacuum rf breakdowns must be overcome [1, 2]. During the development of the Next Linear Collider/Global Linear Collider the statistical nature of rf breakdown became apparent [3, 4, 2]. It was found that when accelerating structures are exposed to constant rf power and pulse shape, the number of rf breakdowns per pulse is nearly constant. The breakdown rate depends on pulse heating [5] and other factors, such as the peak surface magnetic field [6], the peak surface electric field, and the peak Poynting vector [7]. Presently X-band accelerating structures are the most studied in terms of rf breakdowns [2, 8, 9].

Recent research on high gradient rf acceleration found that hard metals, such as hard copper and hard copper-silver, have lower breakdown rate than soft metals [8].

High temperature brazing makes the metal soft, therefore this process cannot be used to manufacture cavities out of

hard metal alloys such as copper-silver.

To avoid high temperature brazing, novel manufacturing techniques were introduced for building accelerating structures. One application is to make structures composed of two halves, joined at the symmetry plane along the beam axis. The cells and the power couplers are milled into each half. In this paper we describe the case where a  $TM_{01}$  mode launcher is used as power coupler. In this particular geometry the currents are flowing through the joint. Therefore the joint has to be brazed or clamped to provide electrical integrity.

This mode launcher transforms the  $TE_{10}$  mode of the rectangular waveguide to the  $TM_{01}$  mode of circular waveguide. The original mode launcher design was presented in [10, 11] for the NLC project. This mode launcher had sharp internal corners difficult to be manufactured by milling.

## DESIGN CONSIDERATIONS

This mode launcher, designed for the CERN CLIC [12] working frequency  $f = 11.9942$  GHz, will be milled with a 8 mm diameter tool. This means that the edges of the rectangular waveguides and other parts must have a radius of 4 mm, or larger. There must be no electric field enhancement in the iris, in other words the iris impedance must have low capacitive component. The mode launcher has to satisfy the following specifications: peak surface electric field  $< 100$  MV/m, peak surface pulsed heating  $< 50$  K, for an input power of 100 MW.

## GEOMETRY

We designed the mode launcher composed of two separate metal halves. Both input and output waveguides and the coupling iris are milled into metal blocks. All the edges have been rounded to minimize the peak surface fields. When the two halves are joined together, they form the complete mode launcher. Fig. 1 shows a solid model of half mode launcher. The solid model of one quarter of the mode launcher geometry, simulated with HFSS [13], is in Fig. 2, the waveguide and other dimensions are listed in Fig. 3. Fig. 4 shows the scattering parameters as a function of the frequency, for the final design. The bandwidth is 60 MHz calculated at -30 dB of reflection.

### *Peak surface fields and peak surface pulsed heating*

The peak surface electric field is 53 MV/m, the peak surface magnetic field is 150 kA/m, for the input power  $P_{in} = 100$  MW. They are shown in Fig. 5. For square pulse

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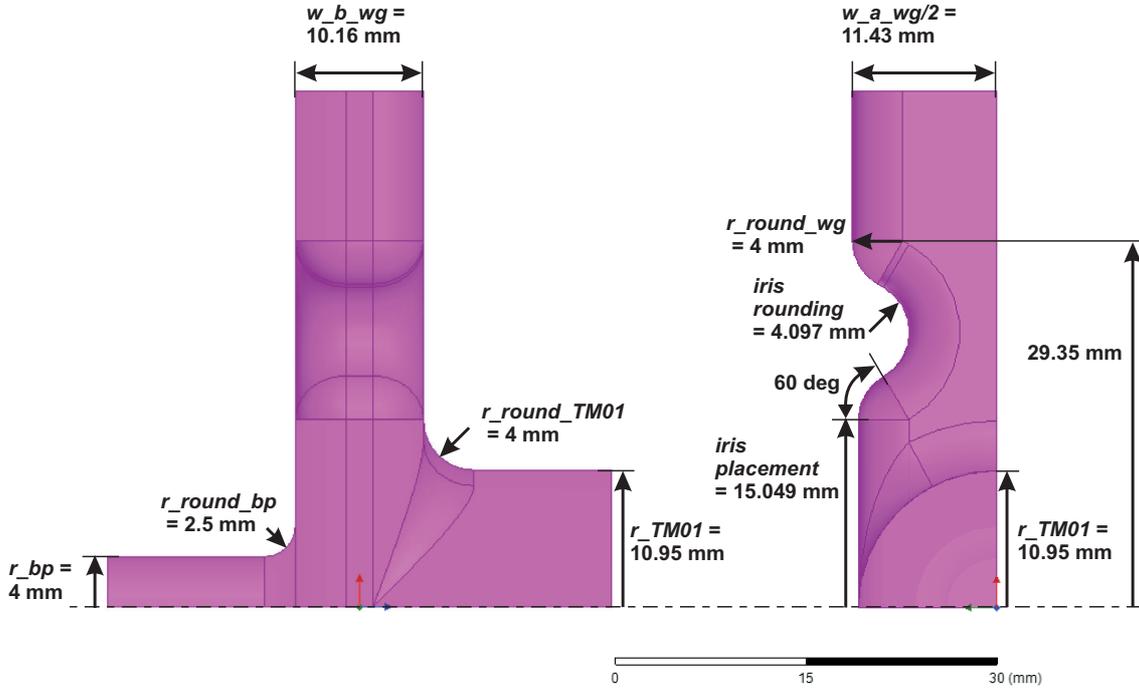


Figure 3: Vacuum part of one quarter of the mode launcher, with dimensions.

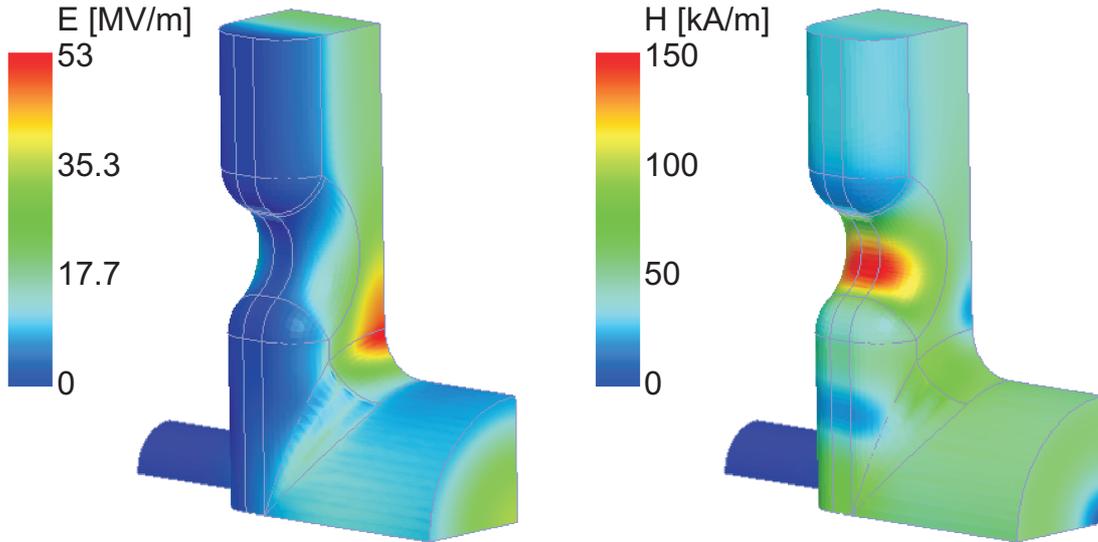


Figure 5: Electric and magnetic peak surface fields of one quarter of the mode launcher, with an input power  $P_{in} = 100$  MW.

length  $t = 2 \mu s$ , we evaluated the peak surface pulsed heating with the following formula [5]:

$$\Delta T = 430 \cdot (H[MA/m])^2 \cdot \sqrt{t[\mu s]} \sqrt{\frac{f[GHz]}{11.424}} = 14 K$$

### TOLERANCE ANALYSIS

We performed the tolerance analysis for the mode launcher. We changed one dimension at the time and calculated the frequency sweep of the rf scattering parameters. We are interested in seeing the sensitivity of the three pa-

rameters: *iris rounding*, distance of the iris with respect to the central axis (*iris placement*) and of the dimension *r\_round\_TM01* of Fig. 3.

Fig. 6 shows the reflection coefficient as a function of the frequency when the dimension of the iris rounding is changed. Nominal curve (blue curve), variation of *iris rounding* of  $+50 \mu m$  (red curve), variation of *iris rounding* of  $-50 \mu m$  (green curve).

Fig. 7 shows the reflection coefficient as a function of the frequency when the iris distance with respect the central

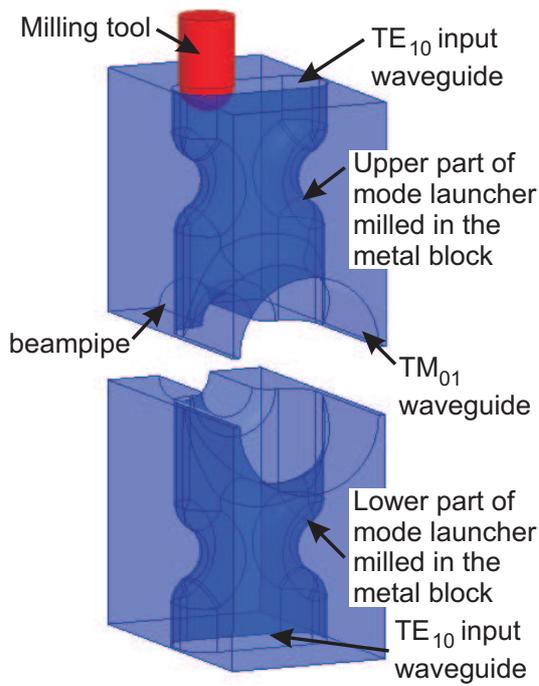


Figure 1: Solid model of half mode launcher, with detail of milling tool.

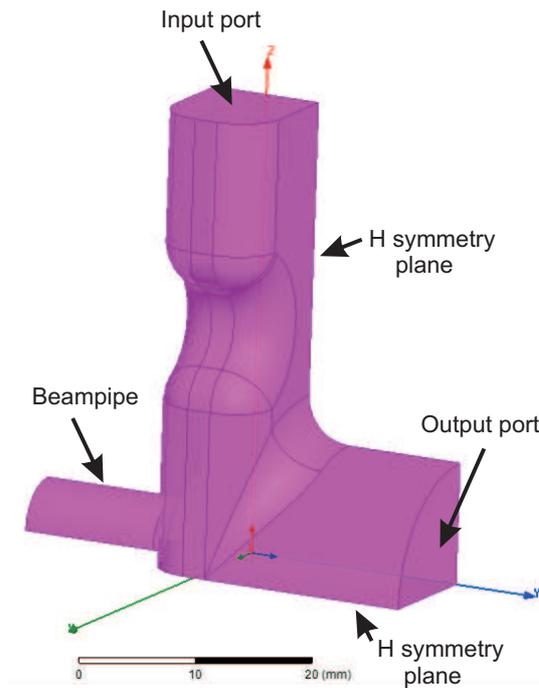


Figure 2: Vacuum part of one quarter of the mode launcher (3D view).

axis is changed. Nominal curve (blue curve), variation of *iris placement* of + 50  $\mu\text{m}$  (red curve), variation of *iris placement* of - 50  $\mu\text{m}$  (green curve).

Fig. 8 shows the reflection coefficient as a function of the frequency when the dimension  $r_{\text{round\_TM01}}$  of

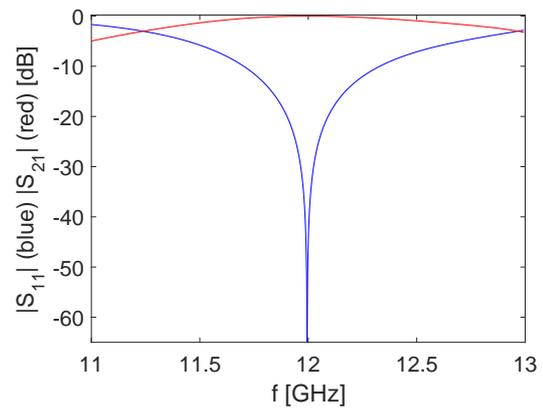


Figure 4: Scattering parameters as a function of the frequency, for the final mode launcher design.

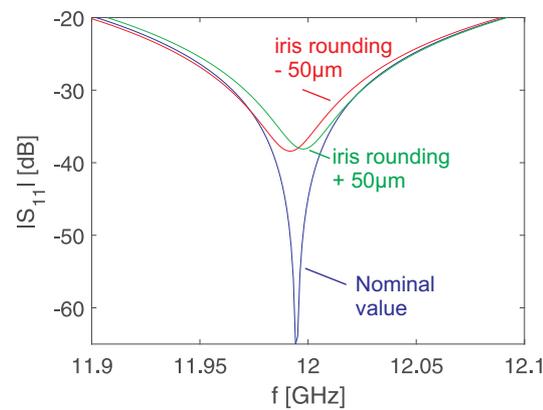


Figure 6: Input reflection coefficient as a function of the frequency. Nominal curve (blue curve), variation of *iris rounding* of + 50  $\mu\text{m}$  (red curve), variation of *iris rounding* of - 50  $\mu\text{m}$  (green curve).

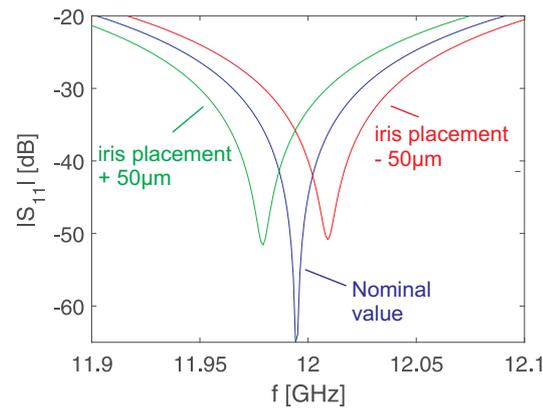


Figure 7: Input reflection coefficient as a function of the frequency. Nominal curve (blue curve), variation of *iris placement* of + 50  $\mu\text{m}$  (red curve), variation of *iris placement* of - 50  $\mu\text{m}$  (green curve).

Fig. 3 is changed. Nominal curve (blue curve), variation of  $r_{\text{round\_TM01}}$  of  $+100 \mu\text{m}$  (red curve), variation of  $r_{\text{round\_TM01}}$  of  $-100 \mu\text{m}$  (green curve).

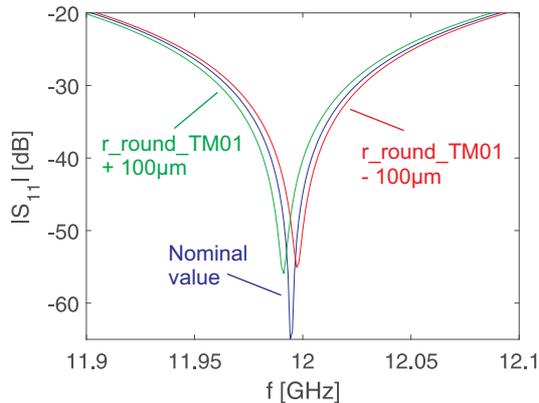


Figure 8: Input reflection coefficient as a function of the frequency. Nominal curve (blue curve), variation of  $r_{\text{round\_TM01}}$  of  $+100 \mu\text{m}$  (red curve), variation of  $r_{\text{round\_TM01}}$  of  $-100 \mu\text{m}$  (green curve).

## CONCLUSIONS

We designed a 11.9942 GHz mode launcher optimized for manufacturing by milling. The parameters of the mode launcher are: reflection = -65 dB (@  $f = 11.9942$  GHz), 60 MHz bandwidth calculated at -30 dB of reflection, peak surface electric field = 53 MV/m, peak surface magnetic field = 150 kA/m, peak pulsed surface heating = 14 K, for a square rf pulse with 100 MW of peak power and  $2 \mu\text{s}$  of pulse length. The mode launcher has practical machining tolerances.

## ACKNOWLEDGMENT

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